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# RESEARCH MEMORANDUM

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PHYSICAL PROPERTIES OF GLASS-FABRIC  
UNSATURATED-POLYESTER LAMINATES

By John E. Wier, Dorothy C. Pons, and  
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National Bureau of Standards

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PHYSICAL PROPERTIES OF GLASS-FABRIC  
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## SUMMARY

The effects of humidity during fabric conditioning and during fabrication upon some physical properties of laminates prepared with glass-fabric, Fiberglas 181-114, and an unsaturated-polyester resin, Laminac 4126, were investigated.

Relative humidity during fabric conditioning and during fabrication was varied from about 4 to 95 percent. Molding pressures were 0.7 and 2.0 psi. The molding temperature recommended by the manufacturer was 220° to 250° F. Preliminary experiments showed the following to be the best times for the temperatures used: For 250° F, 2 hours; for 220° F, 3 hours; and for 160° F, 48 hours.

Tests on these laminates included the measurement of flexural strength on the diagonal, both dry and after 7 days' immersion in water, specific gravity, resin content, percentage of voids, and total light transmission. Some data were also taken on lengthwise flexural strength.

The effects of humidity during fabrication on flexural strength, both wet and dry, and on specific gravity, percentage of voids, and light transmission were pronounced when molding temperatures of 220° and 250° F were used. At a molding temperature of 160° F these effects were negligible.

An increase in the humidity during fabrication decreased the flexural strength, the resin content, the specific gravity, and the light transmission and increased the percentage of voids in laminates molded at 220° and 250° F. For example, when the relative humidity was increased from about 5 to 50 percent during resin coating, the flexural strengths, lengthwise and diagonal and wet or dry, decreased about 15 to 20 percent for laminates made using the 220° F cure and about 35 to 40 percent for the 250° F cure.

Differences in the properties of laminates made of fabric which was dried over silica gel and those made of fabric which was oven-dried were negligible.

A relationship was shown to exist between flexural strength and the percentage of voids, and between the percentage of voids and light transmission.

## INTRODUCTION

The use by the aircraft industry of glass-fabric polyester laminates for semistructural parts such as radomes makes it desirable to attain good quality control of this material. To achieve this, it is necessary to have some knowledge of the effects of the fabrication variables on the physical properties of this type of laminate. To obtain such information, this investigation was conducted at the National Bureau of Standards under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics. The variables studied in the two previous phases of this investigation included molding conditions and fabric finishes, and the results were reported previously (references 1 and 2).

In the course of these experiments considerable variations in the properties of similarly fabricated samples were in evidence. It was suspected that some of these differences in properties could be partially attributed to variations in humidity during the fabrication of these laminates. Accordingly, a group of experiments was made to determine the effects, if any, of humidity during fabrication and during fabric conditioning on the physical properties of one glass-fabric polyester laminate. This report summarizes the results of these experiments.

The assistance of Mr. John Mandel, who made the statistical analysis of the results, is greatly appreciated.

## MATERIALS

The glass fabric selected for this investigation was Fiberglas 181-114, an eight-shaft harness-weave fabric, with a water-repellent methacrylic chrome complex finish (reference 3). Fiberglas 181 is identical to the one used in earlier phases of this investigation (references 1 and 2) and was selected on the basis of the manufacturer's recommendation. The choice of Finish 114 was based both on the manufacturer's recommendation and on results obtained in the second phase of

this investigation (reference 2), which dealt with the effects of fabric finishes on some physical properties of glass-fabric polyester laminates.

The resin, Laminac 4126, was selected on the basis of comparative data obtained on several polyester laminates by investigators at The Johns Hopkins University (reference 4). Further investigations with Bakelite resin XRS-81, which was used in the previous phases of this work, were abandoned because of the discontinuance of its production.

The catalyst was benzoyl peroxide, Luperco ATC in paste form. This paste catalyst consists of 50 percent peroxide in tricresyl phosphate.

The cellophane used as a release agent was Sylphrap No. 600 P-1-L.

#### DEFINITIONS

Flexural strength S: For a beam of rectangular cross section subjected to a concentrated load at midspan:

$$S = \frac{3}{2} \frac{PL}{bd^2}$$

where

P            maximum load  
L            span or distance between supports  
b            width of beam  
d            depth of beam

Resin content: Amount by weight of resin in laminate.

Percentage of voids: Estimated volume of voids  $V_v$  in a specimen expressed in percent of the measured volume  $V_s$  of the specimen:

$$V_v = V_s - V_s'$$

where

$V_s$             volume of specimen obtained by weighing in water and in air

$V_s'$  volume of specimen calculated on assumption of no voids and using measured weight of resin and of glass fabric in specimen and known values for density of glass fabric and resin

Percent light transmission: Ratio of total amount of light transmitted by a flat specimen to amount of light incident normal to specimen expressed as percent.

## PROCEDURES AND EQUIPMENT

### Fabrication of Laminates

Preparation of glass fabric.- The fabric was cut into pieces 6.5 inches square. To keep the fibers of the fabric from unweaving during the impregnation process, the edges of each piece of fabric were coated with starch.

Conditioning of glass fabric.- The fabric used in the experiments to determine suitable molding cycles was dried in an air-circulating oven for one hour at 275° F.

In that portion of this investigation directed at studying the effects of humidity during fabrication, the fabric conditioning included the following treatments: (a) Drying in an oven for 1 hour at 275° F, the same as was done in the molding-cycle experiments, (b) drying over silica gel for a period of not less than 7 days, and (c) conditioning at 95- to 100-percent relative humidity for a period of 16 to 24 hours.

Preparation of resin.- The resin, Laminac 4126, was mixed with 2 percent benzoyl peroxide, Luperco ATC, in batches of 400 to 500 grams. The mixture of resin and catalyst was stirred for a period of 20 minutes with an electrically powered propeller-type stirrer. To minimize the escape of the more volatile components of the resin, the mixing jar was covered almost completely during stirring.

Impregnation of fabric with resin.- The fabric was impregnated with resin by running it through a pair of hand-operated squeeze rollers which were kept coated with resin. Each square of fabric was run between the rollers as many times as was required for the fabric to lose its opacity. Uniform translucency of the fabric was considered to be the criterion of sufficient impregnation. All resin coating was done in a controlled-humidity chamber which is described later.

Panel assembly.- A small amount of resin was applied to a flat piece of cellophane. The seven squares of resin-impregnated fabric were

laid up successively on this area. A small amount of additional resin was applied between plies both to insure an adequate amount of resin and to minimize entrapped air. Another piece of cellophane was placed over the top of the laminate. Air pockets were eliminated by running a spatula over the surface of the cellophane. This entire procedure was carried out in the controlled humidity chamber. All pieces of fabric were placed in the humidity chamber about 15 minutes before the resin coating process was begun. Complete assembly of the panels was accomplished in about 10 additional minutes.

After taking the cellophane-wrapped assembly out of this chamber, the ends of the cellophane sheets, which extended beyond the limits of the laminate, were folded over and held in place with paper clips. The lay-up was placed between preheated glass plates and the assembly placed in a laminating press or a circulating-air oven, depending upon the molding cycle used. (See molding conditions.)

Controlled-humidity chamber.- The controlled-humidity chamber was a cabinet approximately 6 by  $2\frac{1}{2}$  by 2 feet. The front of the chamber was equipped with a sliding door with two armholes to which were attached some flexible vinyl-plastic sleeves to serve as a moisture barrier. The flexibility of the sleeves allowed the operator sufficient freedom of movement to perform the necessary operations. Rubber gloves were worn by the operator to prevent the atmosphere in the laminating chamber from picking up moisture from his hands and arms.

Low relative humidity, 4 to 10 percent, was maintained in the chamber by recirculating the air over trays of silica gel. For 45- to 50-percent relative humidity, the trays were filled with a salt solution of quarts-hydrate calcium nitrate  $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ . For 95- to 100-percent relative humidity the trays were filled with water. The silica gel was changed at least once every 8 hours of operation. After several hours of exposure to resin vapors, the silica gel lost a great deal of its desiccating efficiency. The efficiency of the gel could not be restored by heating. To attain high humidities it was necessary to use hot water initially in the trays. Once the atmosphere in the chamber attained the high humidity, the maintenance of this condition was not difficult.

Humidity was measured with a pair of wet and dry bulb thermometers inserted into the chamber through an opening in the side. The thermometers were placed directly over the exhaust end of the blower system.

To allow the operator to observe the preparation of the laminate, the humidity chamber was equipped with a glass top, had a small glass table inside, and a window in the bottom with a light below.

Molding and humidity conditions.- To determine suitable molding cycles, duplicate panels were molded at 265° F for 1 hour, at 250° F for 1, 2, and 3 hours, at 220° F for 1.5, 3, and 6 hours, at 160° F for 24 and 48 hours, and at 160° F for 48 hours, with an additional cure at 250° F for 2 hours. The fabric used in making these panels was oven-dried for a period of 1 hour at 275° F and the resin coating was done at a humidity of 4 to 8 percent. On the basis of flexural-strength data, three molding cycles were selected as suitable. These were 160° F for 48 hours, 220° F for 3 hours, and 250° F for 2 hours. To determine the effects of humidity during fabrication on this type of laminate, panels were molded at these three molding cycles and at five different conditions of humidity. These conditions of humidity were as follows:

In condition A, the fabric was oven-dried for a period of 1 hour at 275° F and was resin-coated at a low humidity, 4 to 8 percent.

In condition B, the fabric was dried over silica gel for at least 1 week before being coated with resin. In this condition, the fabric was coated with resin at the same low humidity as that in condition A.

In condition C, the fabric was conditioned over silica gel as in condition B. The coating of the fabric with resin was done at 45- to 50-percent relative humidity.

In condition D, the fabric was conditioned over silica gel as in conditions B and C. The coating of the fabric with resin was done at 95- to 100-percent relative humidity.

In condition E, the fabric was conditioned at 95- to 100-percent relative humidity for a period of 16 to 24 hours. The coating of the fabric with resin was also done at 95- to 100-percent relative humidity.

Triplicate panels were fabricated under each combination of molding cycle and humidity conditions B, C, D, and E. Only single panels were fabricated at condition A and the three molding cycles, since duplicate panels had already been made at these combinations of conditions in determining suitable molding cycles. The pressure used in molding all these panels was 0.7 psi.

Duplicate or triplicate panels were also fabricated at a pressure of 2 psi for conditions A and B at the three molding cycles, and for conditions D and E at a molding cycle of 220° F for 3 hours.

Operation of molding apparatus.- The press used was a 10-ton hand-operated Carver laminating press, Model No. 126, equipped with steam-heated platens and a steam-pressure control valve to regulate the temperature. Temperatures were checked with a mercury thermometer placed

in a well in one platen and were maintained to  $\pm 1^{\circ}$  C. The weight of the movable platen of the press was sufficient to give the desired pressure of 0.7 psi. For pressures of 2 psi, an additional 48-pound weight was used. The press was used for moldings at  $220^{\circ}$  and  $250^{\circ}$  F.

For moldings at  $160^{\circ}$  F a circulating-air oven was used. Dead weights were used to provide the desired pressures of 0.7 and 2.0 psi.

### Testing of the Laminates

Conditioning of specimens prior to testing.- All specimens were conditioned for a minimum of 7 days at a temperature of  $77^{\circ}$  F and 50-percent relative humidity prior to testing.

Flexure tests.- The flexure specimens were cut to a length of 2 to 2.5 inches, depending on the thickness of the laminate. These specimens were machined by dry grinding to a width of  $0.500 \pm 0.005$  inch. The thickness was that of the laminate which varied between 0.08 and 0.10 inch. Thicknesses were measured to  $\pm 0.0002$  inch.

The tests were made on two Baldwin-Southwark universal hydraulic testing machines of the fluid-support Bourdon-tube type. The machines, which had capacities of 2400 and 60,000 pounds, respectively, each had a 240-pound lowest range; the range was accurate to within 1 percent at the loads encountered and was used for all tests. Each machine was located in a room controlled at  $77^{\circ}$  F and 50-percent relative humidity.

A variable-span flexure jig was used for testing the specimen as a simple beam loaded at midspan. The contact edges of the supports and the pressure piece were rounded to a radius of  $1/32$  of an inch. In testing, the span-depth ratio was set at 16 to 1 with the span controlled to  $\pm 0.001$  inch. The speed of testing was in accordance with the formula in Method 1031 of reference 5.

Where duplicate panels were made, 12 specimens oriented in the  $45^{\circ}$  diagonal direction were taken from each panel. Half of them were tested after conditioning for 7 days at  $77^{\circ}$  F and 50-percent relative humidity and half after 7 days' immersion in water at  $77^{\circ}$  F. Tests were made mainly on diagonally oriented specimens because it was believed that the flexure properties for this direction were more sensitive to changes in molding conditions than for the lengthwise direction.

In cases where a triplicate set of panels was fabricated under a particular combination of variables, for one panel six specimens were cut on the diagonal and six in the lengthwise direction of the fabric, three specimens of each kind being tested dry, that is, after 7 days



at 77° F and 50-percent relative humidity, and three wet, that is, after 7 days' immersion in water.

Specific gravity.- Specific gravity was measured on the flexure specimens by the displacement-of-water technique according to Method 5011 of reference 5. An analytical balance was used in weighing the specimens both in air and in water.

Resin content.- The resin content was obtained as follows: For the initial weight of the specimen, the value obtained in determining the specific gravity was used. The specimen, after being tested for flexural strength, was heated for 2 hours at 800° to 900° F in a muffle furnace to remove the resin and fabric sizing. After cooling, the residue of the specimen, that is, the glass fabric remaining, was weighed. The weight of residue was divided by the factor 0.997 to correct for the sizing removed, the corrected value being the initial weight of the glass fabric in the specimen. The factor 0.997 was obtained by comparing the weight of a sample of conditioned glass fabric with the weight of the same sample after being heated similarly to the specimens. The amount by weight of resin in the specimen was taken as the difference between the initial weight of the specimen and the initial weight of the glass fabric in the specimen.

Percentage of voids.- The percentage of voids in a specimen was determined as follows: The volume  $V_g$  of the specimen (see definitions) was calculated from the weight of the specimen in air and in water, determined previously (see section on specific gravity). The volume of resin in the specimen was computed using a value of 1.21 for the specific gravity of the resin. This value was determined experimentally on 10 specimens of pure resin according to Method 5011 of reference 5. The volume of glass in the specimen was computed from its initial weight and specific gravity. The value for the specific gravity of the glass was taken as 2.51.

Light transmission.- Total light transmission was measured according to Method No. 3021 of reference 5.

## RESULTS AND DISCUSSION

The data obtained on panels molded at the 10 different molding cycles used to determine suitable curing cycles are shown in table I. A statistical grouping of the flexural-strength data of table I is shown in table II.

The results of tests obtained on panels made at the five different humidity conditions and molded at three molding cycles are shown in tables III, IV, and V. Grouping of these data according to statistically significant differences in flexural and other properties is shown in tables VI, VII, and VIII.

### Effects of Molding Cycle

The statistical analysis of the flexural-strength data, (tables I and II) on panels molded at 10 different combinations of time and temperature indicates that panels molded for 2 hours at 250° F, for 3 hours at 220° F, and for 48 hours at 160° F had equal or higher dry strengths than panels molded for shorter and longer periods of time at these temperatures. Accordingly these cure cycles were selected for the subsequent experiments on the effects of humidity during fabrication.

It is noted that panels molded at 265° F for 1 hour were significantly lower in strength than panels molded at any of the other nine molding conditions. Laminates molded at 160° F for 48 hours with an additional cure of 2 hours at 250° F did not differ significantly in strength (table II) from those molded at 160° F for 48 hours with no additional cure.

Data on the other properties of these laminates (table I) reveal no differences in values which would affect the selection of the molding cycles to be used for the study of the effects of humidity.

Values of other properties of panels molded at the three cycles selected as suitable are incorporated into tables III, IV, and V. Discussion of these properties of the panels is included in the effects of humidity on each of the various properties.

### Effects of Humidity During Fabrication

Tables III to VIII and figures 1 to 9 show data on laminates molded at the three molding cycles and fabricated at the five different conditions of humidity.

Effects of humidity on dry flexural strength.- Table III and figure 1 show the dry diagonal flexural strength of laminates fabricated at these five different conditions of humidity and molded at the three different curing cycles. Table VI shows the statistical grouping of the data.

The essence of the flexural-strength results, as shown by this table and by figure 1, is as follows: Varying the relative humidity

during conditioning and resin coating has no significant effect on the dry strength of panels cured at 160° F for 48 hours but has a marked effect on the strength of laminates cured at the recommended temperatures, 220° to 250° F. Thus as the relative humidity during resin coating is increased, the flexural strength is much reduced with the reduction greater for 250° than for 220° F cure.

The magnitudes of these changes for laminates made at 0.7 psi are as follows:

For the two low humidity conditions A and B, the dry flexural strengths, about 24,500 psi, do not differ significantly at 220° and 250° F but are slightly, although significantly, less than 27,500 psi, the value for the 160° F, 48-hour cure.<sup>1</sup> For the moderate condition C, in which the relative humidity was 50 percent during resin coating, the resulting flexural strengths for the 220° and 250° F cures, 20,500 and 17,000 psi, respectively, are already appreciably as well as significantly lower than the values for resin coating in dry air (A and B).

For cures at 220° and 250° F at the times selected, the effect of resin coating at 95-percent relative humidity as in conditions D and E is the reduction of the strength to average values of about 14,000 and 11,000 psi, respectively. It should be noted that the beneficial effect of drying the fabric over silica gel in condition D is practically nullified by the high humidity during resin coating since for conditions D and E at the 220° and 250° F cures the strengths were reduced to nearly the same level.

Since conditions A and B are quite similar and also D and E, it was decided to analyze statistically data for a pressure of 0.7 psi for the above conditions; the results of this analysis are shown in table VII. This table shows that for each molding cycle panels fabricated at condition A are not significantly different in strength from panels molded at condition B.

Table VII also shows that panels molded at condition D do not differ significantly in strength from panels molded at condition E, at 250° and 160° F. Panels made at condition D are shown to have a significantly higher strength than those made at condition E, at 220° F. There is little, if any, logical explanation for this apparent anomaly, so it must be ascribed to chance fluctuations.

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<sup>1</sup>It is interesting to note that in previous work (reference 1) with a different polyester resin, the highest strengths were obtained with a similar long cure at 160° F in contrast with cures at the recommended temperatures which were much higher.

It is interesting to note that the dry flexural strengths for panels prepared at all humidity conditions and cured at 160° F for 48 hours were significantly higher (at the 99.9 percent level of confidence) than their values for other cures with any humidity condition.

Effects of humidity on wet diagonal flexural strength.- Table III shows the strength of laminates molded at the different conditions of humidity and temperature, tested wet after 7 days' immersion in water.

A comparison of figures 1 and 2 shows that the trends for the different humidity conditions of wet strength as the molding temperature is increased are very similar to those for dry diagonal flexural strength. Likewise, the statistical grouping of the wet-strength data is similar to that for dry diagonal flexural strength. As before at the 160° F cure there is little effect from varying the humidity during fabrication, whereas for the 220° and 250° F cures the strength diminishes with increasing humidity.

The diagonal flexural strength of panels molded at 0.7-psi pressure ranged as follows:

- (1) For a molding temperature of 250° F from 7200 psi at condition D to 17,900 psi in panels made at condition A
- (2) For a molding temperature of 220° F from 8900 psi in panels made at condition E to 17,100 psi in panels made at condition A
- (3) For a molding temperature of 160° F from 17,500 psi in panels made at condition D to 19,900 psi in panels made at condition A

To summarize the effects of varying the humidity during resin coating on the dry and wet diagonal flexural strengths, these properties for conditions B, C, and D may be expressed in percent of the value at condition B as follows:

| Cure temperature<br>(°F) | Condition and relative humidity during coating |   |                                 |                                 |
|--------------------------|--|---|---------------------------------|---------------------------------|
|                          | Condition when tested                          | B, 5-percent relative humidity                            | C, 50-percent relative humidity | D, 95-percent relative humidity |
|                          |  | Flexural strength<br>(percent of strength at condition B) |                                 |                                 |
| 250                      | Dry  | 100   | 66                              | 42                              |
|                          | Wet  | 100   | 65                              | 42                              |
| 220                      | Dry  | 100   | 85                              | 64                              |
|                          | Wet  | 100   | 83                              | 55                              |
| 160                      | Dry  | 100   | 96                              | 93                              |
|                          | Wet  | 100   | 103                             | 95                              |

Effects of humidity on flexural strength, lengthwise.- Flexural strength lengthwise (table IV) was affected by humidity during fabrication in the same manner as was the flexural strength on the diagonal.

The values for lengthwise strength varied from 14,900 psi in panels made at condition E and molded at 250° F to 45,000 psi in panels made at condition A and molded at 160° F at the same pressure.

Wet flexural strength lengthwise ranged from 10,200 psi in panels made at condition D and molded at 250° F to 34,800 psi in panels made at condition B and molded at the same temperature.

Effects of humidity on percent loss in strength due to water immersion.- The percent loss in diagonal flexural strength due to water immersion is given in tables III and VI. It ranged from 25.4 percent for panels made at condition E and molded at 250° F to 40.6 percent in panels made at condition D and molded at 220° F.

The data show considerable scatter and no definite conclusions regarding any definite trends appear justified. An exception to this general statement occurred for panels molded at condition D at 220° F. Panels molded at this condition and temperature show a 40-percent loss in

strength which is much higher than in panels made at any of the other conditions. Two panels molded at 2.0 psi exhibited similar high losses. The reason for this apparent anomaly is not clear, especially since panels fabricated at condition E, a somewhat similar condition, displayed no unduly high percent loss of strength due to water immersion.

Effects of humidity on specific gravity.-- For a molding pressure of 0.7 psi the specific gravity (tables V and VIII, fig. 3) varied from 1.32 in panels made at condition D and molded at 250° F to 1.66 in panels made at condition E and molded at 160° F.

The most significant differences occurred in panels fabricated at conditions E, D, and C at temperatures of 250° and 220° F. Panels molded at these temperatures at conditions A and B, and those molded at 160° F at all five humidity conditions showed no significant differences in specific gravity.

Effects of humidity on resin content.-- The resin contents of panels made at the different humidities and molding cycles are shown in tables V and VIII and figure 4. The resin content varied from 31.1 percent in panels made at condition E and molded at 250° F to 46.0 percent in panels made at condition A and molded at 160° F.

The influence of humidity on resin content is least for cures at 160° F and greatest for cures at 250° F. Thus, while the general trend for each cure temperature is a decrease in resin content as the humidity during fabrication is increased, for cures at 160° F the resin-content values, except for condition E, did not differ significantly from one another (table VIII). For cures at 250° F, however, the resin contents for conditions A, B, C, D, and E were successively lower in that order and significantly so.

Effects of humidity on voids.-- Data on voids are given in tables V and VIII and figure 5. The effect of humidity during fabrication on the voids content is somewhat similar to that for resin content. Thus, the influence of humidity is least for cures at 160° F and greatest for cures at 250° F. The general trend for each cure temperature is an increase in voids content as the humidity during fabrication is increased. However, as indicated in table VIII, for cures at 160° F the values for voids content for conditions A to E do not differ significantly, the range being -0.2 to 1.2 percent.<sup>2</sup> For panels molded at 250° F the voids

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<sup>2</sup>The reason for obtaining a negative voids content in some panels is that this calculation is based on the specific gravity of the resin as obtained commercially. However, in molding the panels at a temperature of 160° F some of the styrene monomer is lost before the resin is fully cured. Since the styrene is the low-density component of the copolymer, a decrease in the styrene content of the resin will result in a copolymer of higher density than that of the original resin, as received from the manufacturer.

contents ranged from about 1.6 percent for conditions A and B to 25.7 percent for condition D. It is noted that the values for the voids content of the panels molded at 220° and 250° F with humidity conditions A and B were 2 percent or less and did not differ significantly from the corresponding data for panels molded at 160° F.

Panels molded at 250° F had a significantly higher voids content than those molded at 220° F for the higher humidity conditions C, D, and E; for the low humidity conditions the voids values for the panels molded at 220° and 250° F did not differ significantly.

Effects of humidity on light transmission.- Data on light transmission of panels made at the various humidity conditions and temperatures are shown in tables V and VIII and figure 6. For panels molded at 0.7 psi the light transmission increased from 1 percent in panels made at condition D and molded at 250° F to 50 percent in panels made at condition A and molded at 160° F.

Light-transmission data were gathered in the belief that the degree of translucency of a panel was an indication of the intimacy of the resin-fabric bond.

Panels made at all conditions of humidity except E, and molded at 160° F, had the highest degree of translucency. Light transmission for these panels ranged from 35 to 50 percent. Panels molded at condition E, at this temperature, had a light transmission of 14 percent.

Panels molded at 220° and 250° F ranged in light transmission from 1 to 15 percent, depending upon the humidity conditions at which they were fabricated. It is noted that for the low humidity conditions A and B, and cures at both 220° and 250° F, the light-transmission values did not differ significantly.

#### Relationships between Properties

Relationship of wet to dry strength.- The relationship of wet to dry diagonal flexural strength is illustrated in figure 7. Since this appears almost as a straight line, it can be concluded that the wet strength of a panel is directly dependent upon its dry strength. Departures from the straight line may be explained by the fact that wet- and dry-strength data must be obtained on two different specimens and hence the ratio of the two strengths is somewhat influenced by specimen-to-specimen variability of the results. It should not be inferred that laminates made with different glass fabric, fabric finish, or resin would necessarily show this same relationship between dry and wet strength.

Relationship between voids content and flexural strength.- The flexural strength of a glass-fabric laminate bonded with Laminac 4126 is definitely related to its voids content. The strength increases as the amount of voids is decreased. This relationship is illustrated in figure 8. The existence of such a relationship emphasizes the necessity of quantitative measurement of voids in this type of laminate, and the need for developing laminating techniques which reduce the amount of voids to a minimum.

Relationship of light transmission to voids.- It has been remarked in the section on the effects of humidity on light transmission, that this property is believed to be a measure of the intimacy of the resin glass-fiber bond. Since in some respects voids are also a measure of this property, it could be expected that a relationship exists between the light transmission and the amount of voids in the laminate. This relationship is shown in figure 9.

#### STATISTICAL ANALYSIS

The flexural-strength data in table III were initially treated by "Analysis of Variance." The presence of considerable interaction between relative humidity and molding temperature shown by these analyses made a different method of analysis more desirable. The procedure, which was applied to all the data in the table, is based on ranking of the data for each property such as dry flexural strength, according to increasing values of this property for the various molding conditions. It was then tentatively assumed that all averages belonged to the same statistical population. Subsequently this hypothesis was abandoned whenever the differences between successive averages exceeded what might be expected on the basis of chance. As a result of this treatment separations in the series of averages were made on two different levels of confidence, namely, 99.9 and 99 percent. A double line in the table, corresponding to a 99.9-percent level of confidence, indicates a relatively high degree of certainty that the separated values belong to different populations. A single line, corresponding to a 99-percent confidence level, indicates a fairly definite separation. A more detailed discussion of this statistical grouping procedure<sup>3</sup> is given in the appendix.

It must be recognized that any grouping procedure will occasionally result in erroneous grouping. Thus, in the case of two different but overlapping populations, it will occasionally happen that an observation belonging to the lower population will equal or even exceed an observation

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<sup>3</sup>The procedure, developed by Mr. John Mandel of the National Bureau of Standards, has not yet been published.



belonging to the higher population. On the other hand there is the risk of erroneously separating observations which actually belong to the same population, but which by chance effects differed more than one would expect. This latter risk, known as the "level of significance", is equal, in the procedure here adopted, to 0.1 and 1 percent for cuts made at the 99.9 and 99 percent levels, respectively.

It will be noted that the application of this procedure occasionally leads to apparently paradoxical situations, namely, when a difference occurring in the central region of a sequence is considered significant, while an even larger difference near the beginning or the end of the sequence is not considered significant. This is due to the fact that in a homogeneous set of observations the middle ones are, on the average, spaced closer than those occurring near the ends. The paradox can be resolved by observing that the problem considered here is not to separate pairs of values, but rather to separate all values into homogeneous groups.

### CONCLUSIONS

This investigation has definitely established that several physical properties of glass-fabric laminates made of Fiberglas 181-114 and bonded with an unsaturated polyester resin, Laminac 4126, are affected by humidity during fabrication if molding is done at the recommended temperatures of 220° to 250° F. It has also been established that these effects of humidity are decreased and almost completely eliminated if molding temperatures of 160° F are employed.

Specifically, these effects can be summarized as follows:

1. At molding temperatures of 220° and 250° F an increase in humidity during fabrication and during fabric conditioning affects the finished laminate as follows:

- a. Decreases its flexural strength, both wet and dry, with a greater effect at 250° F than at 220° F. Thus, for laminates molded at 220° F with a relative humidity during fabrication of 50 percent, the flexural strength is 15 to 20 percent less than that for laminates made at 5-percent relative humidity; at 95-percent relative humidity the flexural strength is 40 to 50 percent less.

- b. Decreases its specific gravity.

- c. Decreases its resin content.

d. Increases its voids content.

e. Decreases its light transmission.

2. At a molding temperature of 160° F, an increase in humidity during fabrication and fabric conditioning produces little or no effect on the properties of the laminate.

This investigation has also established the existence of a relationship between the percentage of voids and the flexural strength of this type of glass-fabric polyester laminate. This emphasizes the need for producing void-free laminates.

It has also been shown that the light-transmission properties of a laminate are related to the percentage of voids. From this relationship it appears that the measurement of this optical property in certain types of laminates may be useful in determining their soundness and as a measurement for quality control.

National Bureau of Standards

Washington, D. C., October 9, 1950

## APPENDIX

## STATISTICAL GROUPING

In order to use the grouping procedure employed in this study it is necessary to know the standard deviation of the individual values in the sequence. Each value listed in the tables is an average of the values for a triplicate set of panels. Each triplicate set of values yields information on the variability of panel averages. By pooling this information for the various sets of triplicates a more reliable estimate of this variability is obtained. The standard error  $s_p$  corresponding to the average of each set of triplicate panels is then easily calculated. The following are the values of  $s_p$  for the various properties:

| Property                          | $s_p$                 |
|-----------------------------------|-----------------------|
| Dry flexural strength             | $0.8 \times 10^3$ psi |
| Wet flexural strength             | $0.6 \times 10^3$ psi |
| Percent loss in flexural strength | 2.24 percent          |
| Resin content                     | 0.74 percent          |
| Specific gravity                  | 0.18                  |
| Voids                             | 0.83 percent          |
| Light transmission                | 2.2 percent           |

The grouping procedure outlined in the section entitled "Statistical Analysis" was carried out. Whenever a 99.9-percent separation or "cut" was made the separated values were considered to belong to different populations and the grouping procedure repeated on the subgroups.

As an additional check on the above grouping, an estimate of the standard deviation corresponding to the averages in a subgroup  $s_r$  obtained from the range of the subgroup was compared with the standard error  $s_p$ . If  $s_r$  was found to be significantly larger than  $s_p$  at the 95-percent level of confidence or better, then it was considered that the subgroup was not homogeneous, that is, it includes two or more overlapping populations. Such subgroups are identified in the table by a bracket and cross. If for a subgroup  $s_r$  was significantly less than  $s_p$  at the 95-percent level, as occurred in table II for loss in flexural strength, the separation was indicated as only tentative.

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TABLE I.- EFFECTS OF DIFFERENT MOLDING CYCLES ON PROPERTIES OF FIBERGLAS 181-114

LAMINATES BONDED WITH LAMINAC 4126 RESIN AT 0.7-PSI PRESSURE

| Molding cycle          |                     | Diagonal flexural strength, dry (psi)<br>(a) | Diagonal flexural strength, wet (psi)<br>(a) | Loss in flexural strength due to water immersion (percent)<br>(b) | Resin content (percent by weight)<br>(c) | Specific gravity<br>(c) | Voids (percent by volume)<br>(c) | Light transmission (percent)<br>(d) |
|------------------------|---------------------|--|--|---|--|-------------------------|----------------------------------|-------------------------------------|
| Temperature (°F)       | Time (hr)           |  |  |   |  |                         |                                  |                                     |
| 265                    | 1                   | $20.6 \times 10^3$                           | $15.6 \times 10^3$                           | 24.5  | 44.1                                     | 1.62                    | 1.9                              | 3                                   |
| 250                    | 1                   | 25.8   | 18.2   | 29.0  | 44.5                                     | 1.63                    | .7                               | 27                                  |
|                        | 2                   | 25.5   | 17.1   | 29.0  | 44.4                                     | 1.63                    | .7                               | 12                                  |
|                        | 3                   | 23.1   | 16.4   | 28.9  | 43.8                                     | 1.62                    | 1.6                              | 18                                  |
| 220                    | 1.5                 | 22.0   | 16.0   | 27.5  | 44.7                                     | 1.62                    | .9                               | 12                                  |
|                        | 3                   | 24.3   | 17.0   | 29.6  | 44.6                                     | 1.64                    | .5                               | 14                                  |
|                        | 6                   | 24.5   | 17.4   | 29.0  | 44.7                                     | 1.64                    | .2                               | 18                                  |
| 160                    | 24                  | 24.9   | 18.6   | 25.5  | 44.3                                     | 1.66                    | -.4                              | 52                                  |
|                        | 48                  | 27.6   | 20.1   | 28.3  | 45.9                                     | 1.63                    | -.3                              | 50                                  |
| <sup>e</sup> 160 - 250 | <sup>e</sup> 48 - 2 | 26.7   | 18.6   | 30.2  | 45.2                                     | 1.64                    | -.2                              | 38                                  |

<sup>a</sup>Data based on results for 12 specimens taken equally from 2 panels.<sup>b</sup>Data based on the average results for six dry and six wet specimens taken from each of two panels.<sup>c</sup>Data based on results for 24 specimens taken equally from 2 panels.<sup>d</sup>Data based on eight readings taken equally on two panels.<sup>e</sup>Molding cycle of 160° F for 48 hr with an additional cure at 250° F for 2 hr.

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TABLE II.- GROUPING OF DIAGONAL-FLEXURAL-STRENGTH DATA OF TABLE I  
ACCORDING TO STATISTICALLY SIGNIFICANT DIFFERENCES

[The notations used for statistical grouping in this table are as follows: A single line between values indicates that the values are statistically different at a level of confidence between 99 and 99.9 percent. A broken line indicates a tentative separation. The symbol }x beside a subgroup indicates that the latter contains overlapping populations.]

| Molding cycle          |                     | Flexural strength, dry (psi) | Molding cycle          |           | Flexural strength, wet (psi) | Molding cycle          |           | Loss in flexural strength due to water immersion (percent) |
|------------------------|---------------------|------------------------------|------------------------|-----------|------------------------------|------------------------|-----------|--|
| Temperature (°F)       | Time (hr)           |                              | Temperature (°F)       | Time (hr) |                              | Temperature (°F)       | Time (hr) |  |
| 265                    | 1                   | 20.6 × 10 <sup>3</sup> } x   | 265                    | 1         | 15.6 × 10 <sup>3</sup>       | 265                    | 1         | 24.5   |
| 220                    | 1.5                 |                              | 220                    | 1.5       |                              | 160                    | 24        | 25.5   |
| 250                    | 3                   |                              | 250                    | 3         |                              | -----                  |           | -----  |
|                        |                     |                              | 220                    | 3         | 17.0                         | 220                    | 1.5       | 27.5   |
|                        |                     |                              | 250                    | 2         | 17.1                         | 160                    | 48        | 28.3   |
|                        |                     |                              | 220                    | 6         | 17.4                         | 250                    | 3         | 28.9   |
| 220                    | 3                   | 24.3 } x                     |                        |           |                              | 250                    | 1         | 29.0   |
| 220                    | 6                   |                              |                        |           |                              | 250                    | 2         | 29.0   |
| 160                    | 24                  |                              | 250                    | 1         | 18.2                         | 220                    | 6         | 29.0   |
| 250                    | 2                   |                              | 160                    | 24        | 18.6                         | 220                    | 3         | 29.6   |
| 250                    | 1                   |                              | <sup>a</sup> 160 - 250 | 48 - 2    | 18.6                         | <sup>a</sup> 160 - 250 | 48 - 2    | 30.2   |
| <sup>a</sup> 160 - 250 | <sup>a</sup> 48 - 2 |                              |                        |           |                              |                        |           |  |
| 160                    | 48                  | 26.7                         | 160                    | 48        | 20.1                         |                        |           |  |
|                        |                     | 27.6                         |                        |           |                              |                        |           |  |

<sup>a</sup>Molded first at a temperature of 160° F for 48 hr and then at a temperature of 250° F for 2 hr.



TABLE III.- DIAGONAL-FLEXURAL-STRENGTH PROPERTIES OF FIBERGLAS

181-114 LAMINATES BONDED WITH LAMINAC 4126 RESIN

AT DIFFERENT MOLDING AND HUMIDITY CONDITIONS

| Molding conditions |                     |              | Humidity conditions<br>(a)  |                        |                        |                        |                        |
|--------------------|---------------------|--------------|---|------------------------|------------------------|------------------------|------------------------|
| Pressure<br>(psi)  | Temperature<br>(°F) | Time<br>(hr) | A   | B                      | C                      | D                      | E                      |
|                    |                     |              | Flexural strength, <sup>b</sup> dry<br>(psi)                                |                        |                        |                        |                        |
| 0.7                | 250                 | 2            | 24.9 × 10 <sup>3</sup>  | 25.2 × 10 <sup>3</sup> | 16.7 × 10 <sup>3</sup> | 10.6 × 10 <sup>3</sup> | 10.8 × 10 <sup>3</sup> |
|                    | 220                 | 3            | 23.5  | 24.0                   | 20.5                   | 15.4                   | 12.0                   |
|                    | 160                 | 48           | 26.9  | 28.2                   | 27.1                   | 26.2                   | 26.4                   |
| 2.0                | 250                 | 2            | 24.9  | <sup>c</sup> 25.7      | -----                  | -----                  | -----                  |
|                    | 220                 | 3            | 25.0  | <sup>c</sup> 26.8      | -----                  | <sup>c</sup> 18.0      | <sup>c</sup> 13.4      |
|                    | 160                 | 48           | 28.2  | <sup>c</sup> 30.2      | -----                  | -----                  | -----                  |
|                    |                     |              | Flexural strength, <sup>b</sup> wet<br>(psi)                                |                        |                        |                        |                        |
| 0.7                | 250                 | 2            | 17.9 × 10 <sup>3</sup>  | 17.6 × 10 <sup>3</sup> | 11.4 × 10 <sup>3</sup> | 7.2 × 10 <sup>3</sup>  | 8.0 × 10 <sup>3</sup>  |
|                    | 220                 | 3            | 17.1  | 16.7                   | 13.8                   | 9.2                    | 8.9                    |
|                    | 160                 | 48           | 19.9  | 18.5                   | 19.0                   | 17.5                   | 18.3                   |
| 2.0                | 250                 | 2            | 19.0  | <sup>c</sup> 18.2      | -----                  | -----                  | -----                  |
|                    | 220                 | 3            | 19.3  | <sup>c</sup> 18.6      | -----                  | <sup>c</sup> 10.6      | <sup>c</sup> 9.4       |
|                    | 160                 | 48           | 21.6  | <sup>c</sup> 20.4      | -----                  | -----                  | -----                  |
|                    |                     |              | Loss in flexural strength due to water immersion, <sup>d</sup><br>(percent) |                        |                        |                        |                        |
| 0.7                | 250                 | 2            | 28.1  | 29.9                   | 31.6                   | 31.9                   | 25.4                   |
|                    | 220                 | 3            | 26.7  | 30.4                   | 32.4                   | 40.6                   | 26.2                   |
|                    | 160                 | 48           | 25.8  | 33.9                   | 29.9                   | 32.8                   | 29.9                   |
| 2.0                | 250                 | 2            | 23.8  | <sup>e</sup> 29.1      | ----                   | -----                  | -----                  |
|                    | 220                 | 3            | 22.9  | <sup>e</sup> 30.7      | ----                   | <sup>e</sup> 41.3      | <sup>e</sup> 30.3      |
|                    | 160                 | 48           | 23.4  | <sup>e</sup> 32.4      | ----                   | -----                  | -----                  |

<sup>a</sup>The preconditioning of the fabric and impregnation of the fabric with resin were done under the following conditions:

Condition A: Fabric oven-dried at 135° C for at least 24 hr and impregnated at a low relative humidity, 4 to 8 percent, at room temperature

Condition B: Fabric dried over silica gel for at least 7 days and impregnated at a low relative humidity, 4 to 8 percent, at room temperature

Condition C: Fabric dried over silica gel for at least 7 days and impregnated at 45- to 50-percent relative humidity

Condition D: Fabric dried over silica gel for at least 7 days and impregnated at 95- to 100-percent relative humidity at room temperature

Condition E: Fabric conditioned and impregnated at 95-percent relative humidity at room temperature

<sup>b</sup>Data based on 15 specimens, 12 being taken equally from 2 panels and 3 from the third, unless otherwise specified.

<sup>c</sup>Data based on 12 specimens taken equally from 2 panels.

<sup>d</sup>Data based on the average of the three panels from which flexural strength specimens were taken, unless otherwise specified.

<sup>e</sup>Data based on the average of the two panels from which flexural strength specimens were taken.



TABLE IV.- LENGTHWISE FLEXURAL-STRENGTH DATA OF FIBERGLAS  
181-114 LAMINATES BONDED WITH LAMINAC 4126 RESIN AT  
DIFFERENT MOLDING AND HUMIDITY CONDITIONS

| Molding conditions |                     |              | Humidity conditions<br>(1)  |                        |                        |                        |                        |
|--------------------|---------------------|--------------|---|------------------------|------------------------|------------------------|------------------------|
| Pressure<br>(psi)  | Temperature<br>(°F) | Time<br>(hr) | A   | B                      | C                      | D                      | E                      |
|                    |                     |              | Flexural strength, <sup>2</sup> dry<br>(psi)                      |                        |                        |                        |                        |
| 0.7                | 250                 | 2            | 41.9 × 10 <sup>3</sup>  | 46.5 × 10 <sup>3</sup> | 28.7 × 10 <sup>3</sup> | 15.7 × 10 <sup>3</sup> | 14.9 × 10 <sup>3</sup> |
|                    | 220                 | 3            | 42.5  | 43.9                   | 35.8                   | 23.4                   | 20.3                   |
|                    | 160                 | 48           | 45.0  | 44.4                   | 43.9                   | 42.8                   | 41.7                   |
| 2.0                | 250                 | 2            | -----   | 46.1                   | -----                  | -----                  | -----                  |
|                    | 220                 | 3            | -----   | 45.1                   | -----                  | -----                  | -----                  |
|                    | 160                 | 48           | -----   | 49.4                   | -----                  | -----                  | -----                  |
|                    |                     |              | Flexural strength, <sup>2</sup> wet<br>(psi)                      |                        |                        |                        |                        |
| 0.7                | 250                 | 2            | 32.1 × 10 <sup>3</sup>  | 34.8 × 10 <sup>3</sup> | 19.2 × 10 <sup>3</sup> | 10.2 × 10 <sup>3</sup> | 12.0 × 10 <sup>3</sup> |
|                    | 220                 | 3            | 32.2  | 31.7                   | 22.3                   | 15.0                   | 17.2                   |
|                    | 160                 | 48           | 33.0  | 32.6                   | 32.3                   | 30.2                   | 32.9                   |
| 2.0                | 250                 | 2            | -----   | 33.8                   | -----                  | -----                  | -----                  |
|                    | 220                 | 3            | -----   | 32.5                   | -----                  | -----                  | -----                  |
|                    | 160                 | 48           | -----   | 33.6                   | -----                  | -----                  | -----                  |
|                    |                     |              | Loss in strength due to water immersion <sup>3</sup><br>(percent) |                        |                        |                        |                        |
| 0.7                | 250                 | 2            | 23.4  | 25.2                   | 33.1                   | 35.0                   | 19.5                   |
|                    | 220                 | 3            | 24.2  | 27.8                   | 37.7                   | 35.9                   | 15.3                   |
|                    | 160                 | 48           | 26.7  | 26.6                   | 26.4                   | 29.4                   | 21.1                   |
| 2.0                | 250                 | 2            | ----  | 26.7                   | ----                   | ----                   | ----                   |
|                    | 220                 | 3            | ----  | 28.0                   | ----                   | ----                   | ----                   |
|                    | 160                 | 48           | ----  | 32.0                   | ----                   | ----                   | ----                   |

<sup>1</sup>The preconditioning of the fabric and impregnation of the fabric with resin were done under the following conditions:

Condition A: Fabric oven-dried at 135° C for at least 24 hr and impregnated at a low relative humidity, 4 to 8 percent, at room temperature

Condition B: Fabric dried over silica gel for at least 7 days and impregnated at a low relative humidity, 4 to 8 percent, at room temperature

Condition C: Fabric dried over silica gel for at least 7 days and impregnated at 45- to 50-percent relative humidity

Condition D: Fabric dried over silica gel for at least 7 days and impregnated at 95- to 100-percent relative humidity at room temperature

Condition E: Fabric conditioned and impregnated at 95-percent relative humidity at room temperature

<sup>2</sup>Data based on three specimens taken from one panel.

<sup>3</sup>Data based on difference of dry and wet strengths as given in upper portions of this table.





TABLE V.- DENSITY AND LIGHT-TRANSMISSION PROPERTIES OF FIBERGLAS  
181-114 LAMINATES BONDED WITH LAMINAC 4126 RESIN AT  
DIFFERENT MOLDING AND HUMIDITY CONDITIONS

| Molding conditions |                     |              | Humidity conditions<br>(a)                        |                   |       |                   |                   |
|--------------------|---------------------|--------------|---|-------------------|-------|-------------------|-------------------|
| Pressure<br>(psi)  | Temperature<br>(°F) | Time<br>(hr) | A   | B                 | C     | D                 | E                 |
|                    |                     |              | Specific gravity <sup>b</sup>                     |                   |       |                   |                   |
| 0.7                | 250                 | 2            | 1.62  | 1.64              | 1.50  | 1.32              | 1.44              |
|                    | 220                 | 3            | 1.62  | 1.62              | 1.55  | 1.48              | 1.50              |
|                    | 160                 | 48           | 1.63  | 1.64              | 1.62  | 1.65              | 1.66              |
| 2.0                | 250                 | 2            | 1.62  | <sup>c</sup> 1.63 | ----- | -----             | -----             |
|                    | 220                 | 3            | 1.63  | <sup>c</sup> 1.64 | ----- | <sup>c</sup> 1.58 | <sup>c</sup> 1.60 |
|                    | 160                 | 48           | 1.65  | <sup>c</sup> 1.67 | ----- | -----             | -----             |
|                    |                     |              | Resin content <sup>b</sup><br>(percent by weight) |                   |       |                   |                   |
| 0.7                | 250                 | 2            | 44.7  | 42.3              | 39.7  | 34.6              | 31.1              |
|                    | 220                 | 3            | 45.1  | 44.1              | 44.1  | 37.0              | 34.2              |
|                    | 160                 | 48           | 46.0  | 45.1              | 45.6  | 43.6              | 41.7              |
| 2.0                | 250                 | 2            | 42.3  | <sup>c</sup> 42.9 | ----- | -----             | -----             |
|                    | 220                 | 3            | 42.3  | <sup>c</sup> 43.2 | ----- | <sup>c</sup> 34.4 | <sup>c</sup> 30.7 |
|                    | 160                 | 48           | 43.3  | <sup>c</sup> 42.7 | ----- | -----             | -----             |
|                    |                     |              | Voids <sup>b</sup><br>(percent by volume)         |                   |       |                   |                   |
| 0.7                | 250                 | 2            | 1.3   | 2.0               | 12.4  | 25.7              | 21.6              |
|                    | 220                 | 3            | 2.0   | 1.9               | 5.8   | 15.2              | 16.3              |
|                    | 160                 | 48           | -.2   | -.1               | .4    | .6                | 1.2               |
| 2.0                | 250                 | 2            | 3.0   | <sup>c</sup> 2.0  | ----- | -----             | -----             |
|                    | 220                 | 3            | 2.6   | <sup>c</sup> 1.2  | ----- | <sup>c</sup> 11.3 | <sup>c</sup> 13.4 |
|                    | 160                 | 48           | .6  | <sup>c</sup> 0    | ----- | -----             | -----             |
|                    |                     |              | Light transmission <sup>d</sup><br>(percent)      |                   |       |                   |                   |
| 0.7                | 250                 | 2            | 11  | 11                | 4     | 1                 | 4                 |
|                    | 220                 | 3            | 14  | 15                | 7     | 7                 | 2                 |
|                    | 160                 | 48           | 50  | 44                | 40    | 35                | 14                |
| 2.0                | 250                 | 2            | 9   | <sup>e</sup> 12   | --    | ---               | --                |
|                    | 220                 | 3            | 10  | <sup>e</sup> 19   | --    | <sup>e</sup> 10   | <sup>e</sup> 2    |
|                    | 160                 | 48           | 47  | <sup>e</sup> 49   | --    | ---               | --                |

<sup>a</sup>The preconditioning of the fabric and impregnation of the fabric with resin were done under the following conditions:

Condition A: Fabric oven-dried at 135° C for at least 24 hr and impregnated at a low relative humidity, 4 to 8 percent, at room temperature

Condition B: Fabric dried over silica gel for at least 7 days and impregnated at a low relative humidity, 4 to 8 percent, at room temperature

Condition C: Fabric dried over silica gel for at least 7 days and impregnated at 45- to 50-percent relative humidity

Condition D: Fabric dried over silica gel for at least 7 days and impregnated at 95- to 100-percent relative humidity at room temperature

Condition E: Fabric conditioned and impregnated at 95-percent relative humidity at room temperature

<sup>b</sup>Data based on 36 specimens taken equally from 3 panels, unless otherwise specified.

<sup>c</sup>Data based on 24 specimens taken equally from 2 panels.

<sup>d</sup>Data based on average of 12 readings taken equally on 3 panels, unless otherwise specified.

<sup>e</sup>Data based on average of eight readings taken equally on two panels.

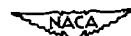


TABLE VI.- GROUPING ACCORDING TO STATISTICALLY SIGNIFICANT DIFFERENCE  
OF DIAGONAL-FLEXURAL-STRENGTH DATA OF TABLE III FOR  
LAMINATES MOLDED AT 0.7-PSI PRESSURE

[The notations used for statistical grouping in this table are as follows: A single line between values indicates that the values are statistically different at a level of confidence between 99 and 99.9 percent. A double line indicates that the values are statistically different at a level of confidence better than 99.9 percent. The symbol }x beside a subgroup indicates that the latter contains overlapping populations.]

| Sample<br>(1) | Flexural<br>strength, dry<br>(psi) | Sample<br>(1) | Flexural<br>strength, wet<br>(psi) | Sample<br>(1) | Loss in<br>strength<br>(percent) |
|---------------|------------------------------------|---------------|------------------------------------|---------------|----------------------------------|
| D1            | $10.6 \times 10^3$                 | D1            | $7.2 \times 10^3$                  | E1            | 25.4                             |
| E1            | 10.8                               | E1            | 8.0                                | A3            | 25.8                             |
| E2            | 12.0                               | E2            | 8.9                                | E2            | 26.2                             |
| D2            | 15.4                               | D2            | 9.2                                | A2            | 26.7                             |
| C1            | 16.7                               | C1            | 11.4                               | A1            | 28.1                             |
| C2            | 20.5                               | C2            | 13.8                               | B1            | 29.9                             |
| A2            | 23.5                               | B2            | 16.7                               | C3            | 29.9                             |
| B2            | 24.0                               | A2            | 17.1                               | E3            | 29.9                             |
| A1            | 24.9                               | D3            | 17.5                               | B2            | 30.4                             |
| B1            | 25.2                               | B1            | 17.6                               | C1            | 31.6                             |
| D3            | 26.2                               | A1            | 17.9                               | D1            | 31.9                             |
| E3            | 26.4                               | E3            | 18.3                               | C2            | 32.4                             |
| A3            | 26.9                               | B3            | 18.5                               | D3            | 32.3                             |
| C3            | 27.1                               | C3            | 19.0                               | B3            | 33.9                             |
| B3            | 28.2                               | A3            | 19.9                               | D2            | 40.6                             |

<sup>1</sup>Alphabetical portion of sample designation refers to humidity condition at which panels were fabricated: A, fabric oven-dried at 135° C for at least 24 hr and impregnated at a low relative humidity, 4 to 8 percent, at room temperature; B, fabric dried over silica gel for at least 7 days and impregnated at a low relative humidity, 4 to 8 percent, at room temperature; C, fabric dried over silica gel for at least 7 days and impregnated at 45- to 50-percent relative humidity; D, fabric dried over silica gel for at least 7 days and impregnated at 95- to 100-percent relative humidity at room temperature; E, fabric conditioned and impregnated at 95-percent relative humidity at room temperature.

Numerical portion of designation refers to molding cycle: 1, 250° F for 2 hr; 2, 220° F for 3 hr; 3, 160° F for 48 hr.

TABLE VII.- GROUPING ACCORDING TO STATISTICALLY SIGNIFICANT DIFFERENCES OF FLEXURAL-STRENGTH DATA

OF TABLE VI FOR PANELS MOLDED AT 0.7-PSI PRESSURE; CONDITIONS A, B, D, AND E, ONLY

[The notations used for statistical grouping in this table are as follows: A single line between values indicates that the values are statistically different at a level of confidence between 99 and 99.9 percent. A double line indicates that the values are statistically different at a level of confidence better than 99.9 percent. The symbol }x beside a subgroup indicates that the latter contains overlapping populations.]

| Sample (1) | Flexural strength, dry (psi) | Sample (1) | Flexural strength, wet (psi) | Sample (1) | Flexural strength, dry (psi) | Sample (1) | Flexural strength, wet (psi) |
|------------|------------------------------|------------|------------------------------|------------|------------------------------|------------|------------------------------|
| A2         | $23.5 \times 10^3$           | B2         | $16.7 \times 10^3$           | D1         | $10.6 \times 10^3$           | D1         | $7.2 \times 10^3$            |
| B2         | 24.0                         | A2         | 17.1                         | E1         | 10.8                         | E1         | 8.0                          |
| A1         | 24.9                         | B1         | 17.6                         | E2         | 12.0                         | E2         | 8.9                          |
| B1         | 25.2                         | A1         | 17.9                         | E2         | 12.0                         | D2         | 9.2                          |
|            |                              | B3         | 18.5                         |            |                              |            |                              |
| A3         | 26.9                         |            |                              | D2         | 15.4                         | D3         | 17.5                         |
| B3         | 28.2                         | A3         | 19.9                         |            |                              | E3         | 18.3                         |
|            |                              |            |                              | D3         | 26.2                         |            |                              |
|            |                              |            |                              | E3         | 26.4                         |            |                              |

<sup>1</sup>Alphabetical portion of sample designation refers to humidity condition at which panels were fabricated: A, fabric oven-dried at 135° C for at least 24 hr and impregnated at a low relative humidity, 4 to 8 percent, at room temperature; B, fabric dried over silica gel for at least 7 days and impregnated at a low relative humidity, 4 to 8 percent, at room temperature; C, fabric dried over silica gel for at least 7 days and impregnated at 45- to 50-percent relative humidity; D, fabric dried over silica gel for at least 7 days and impregnated at 95- to 100-percent relative humidity at room temperature; E, fabric conditioned and impregnated at 95-percent relative humidity at room temperature.

Numerical portion of designation refers to molding cycle: 1, 250° F for 2 hr; 2, 220° F for 3 hr; 3, 160° F for 48 hr.



TABLE VIII.- GROUPING OF SPECIFIC-GRAVITY, RESIN-CONTENT, VOIDS, AND LIGHT-TRANSMISSION DATA  
OF TABLE V FOR LAMINATES MOLDED AT 0.7-P.S.I. PRESSURE ACCORDING TO  
STATISTICALLY SIGNIFICANT DIFFERENCES

[The notations used for statistical grouping in this paper are as follows: A double line between values indicates that the values are statistically different at a level of confidence better than 99.9 percent. The symbol }x beside a subgroup indicates that the latter contains overlapping populations.]

| Sample<br>(1) | Specific<br>gravity | Sample<br>(1) | Resin content<br>(percent by weight) | Sample<br>(1) | Voids<br>(percent by volume) | Sample<br>(1) | Light<br>transmission<br>(percent) |
|---------------|---------------------|---------------|--------------------------------------|---------------|------------------------------|---------------|------------------------------------|
| DL            | 1.32                | E1            | 31.1                                 | A3            | -0.2                         | D1            | 1                                  |
| E1            | 1.44                | E2            | 34.2                                 | B3            | -.1                          | E2            | 2                                  |
| D2            | 1.48                | DL            | 34.6                                 | C3            | .4                           | E1            | 4                                  |
| C1            | 1.50                | D2            | 37.0                                 | D3            | .6                           | C1            | 4                                  |
| E2            | 1.50                | C1            | 39.7                                 | A2            | 1.0                          | D2            | 7                                  |
| C2            | 1.55                | E3            | 41.7                                 | E3            | 1.2                          | C2            | 7                                  |
| A1            | 1.62                | B1            | 42.3                                 | A1            | 1.3                          | B1            | 11                                 |
| B2            | 1.62                | D3            | 43.6                                 | B2            | 1.9                          | A1            | 12                                 |
| A2            | 1.62                | C2            | 44.1                                 | B1            | 2.0                          | A2            | 14                                 |
| C3            | 1.62                | B2            | 44.1                                 | C2            | 5.8                          | E3            | 14                                 |
| A3            | 1.63                | A1            | 44.7                                 | C1            | 12.4                         | B2            | 15                                 |
| B1            | 1.64                | B3            | 45.1                                 | D2            | 15.2                         | D3            | 35                                 |
| B3            | 1.64                | A2            | 45.1                                 | E2            | 16.3                         | C3            | 40                                 |
| D3            | 1.65                | C3            | 45.6                                 | E1            | 21.6                         | B3            | 44                                 |
| E3            | 1.66                | A3            | 46.0                                 | D1            | 25.7                         | A3            | 50                                 |

<sup>1</sup>Alphabetical portion of sample designation refers to humidity condition at which panels were fabricated: A, fabric oven-dried at 135° C for at least 24 hr and impregnated at a low relative humidity, 4 to 8 percent, at room temperature; B, fabric dried over silica gel for at least 7 days and impregnated at a low relative humidity, 4 to 8 percent, at room temperature; C, fabric dried over silica gel for at least 7 days and impregnated at 45- to 50-percent relative humidity; D, fabric dried over silica gel for at least 7 days and impregnated at 95- to 100-percent relative humidity at room temperature; E, fabric conditioned and impregnated at 95-percent relative humidity at room temperature.

Numerical portion of designation refers to molding cycle: 1, 250° F for 2 hr; 2, 220° F for 3 hr; 3, 160° F for 48 hr.



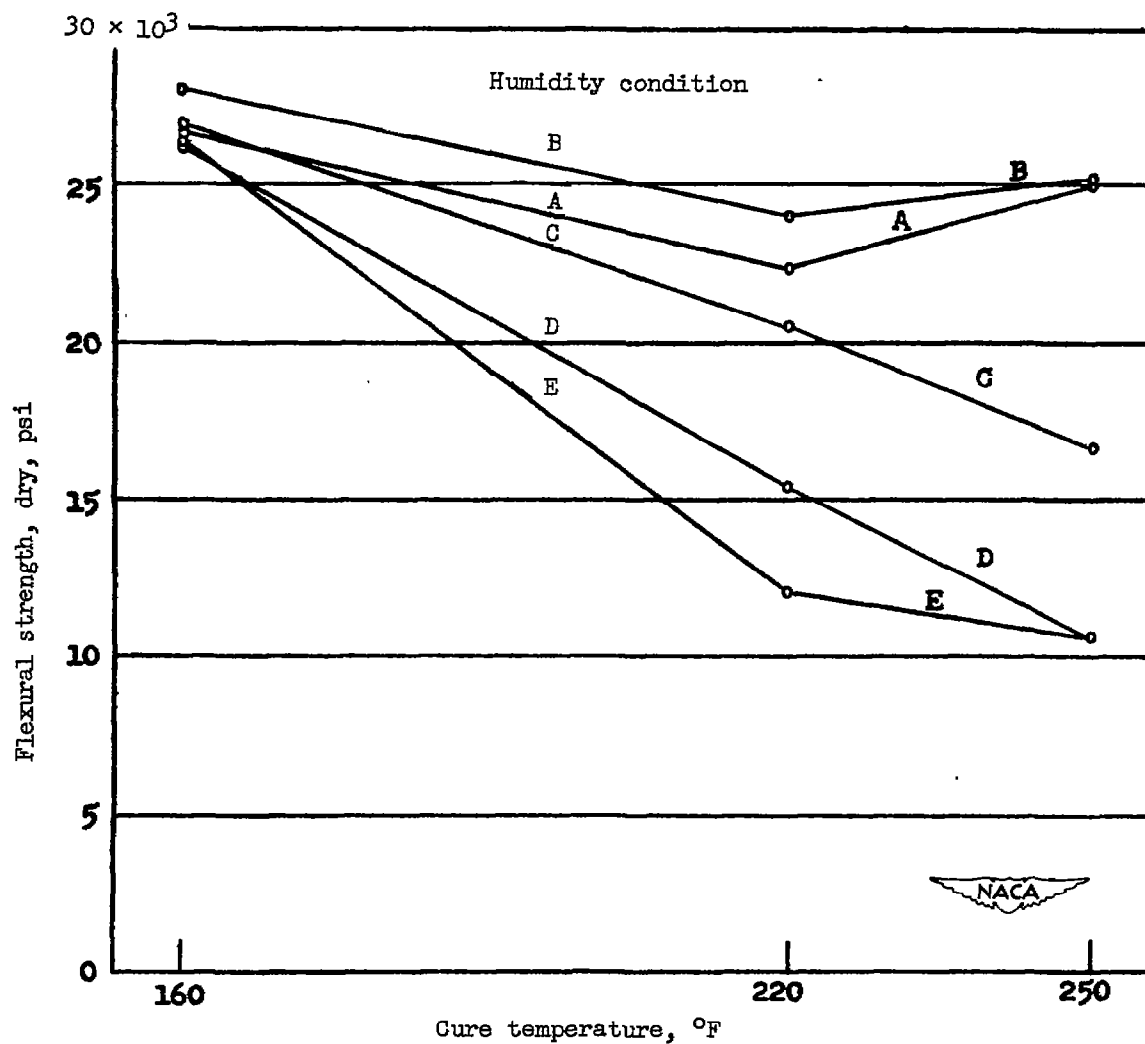


Figure 1.- Effects of cure temperature and humidity during fabrication on the dry diagonal flexural strength of Fiberglas 181-114 laminates bonded with Laminac 4126 resin. Data are for laminates molded at 0.7-psi pressure. See footnote a of table III for description of humidity conditions.

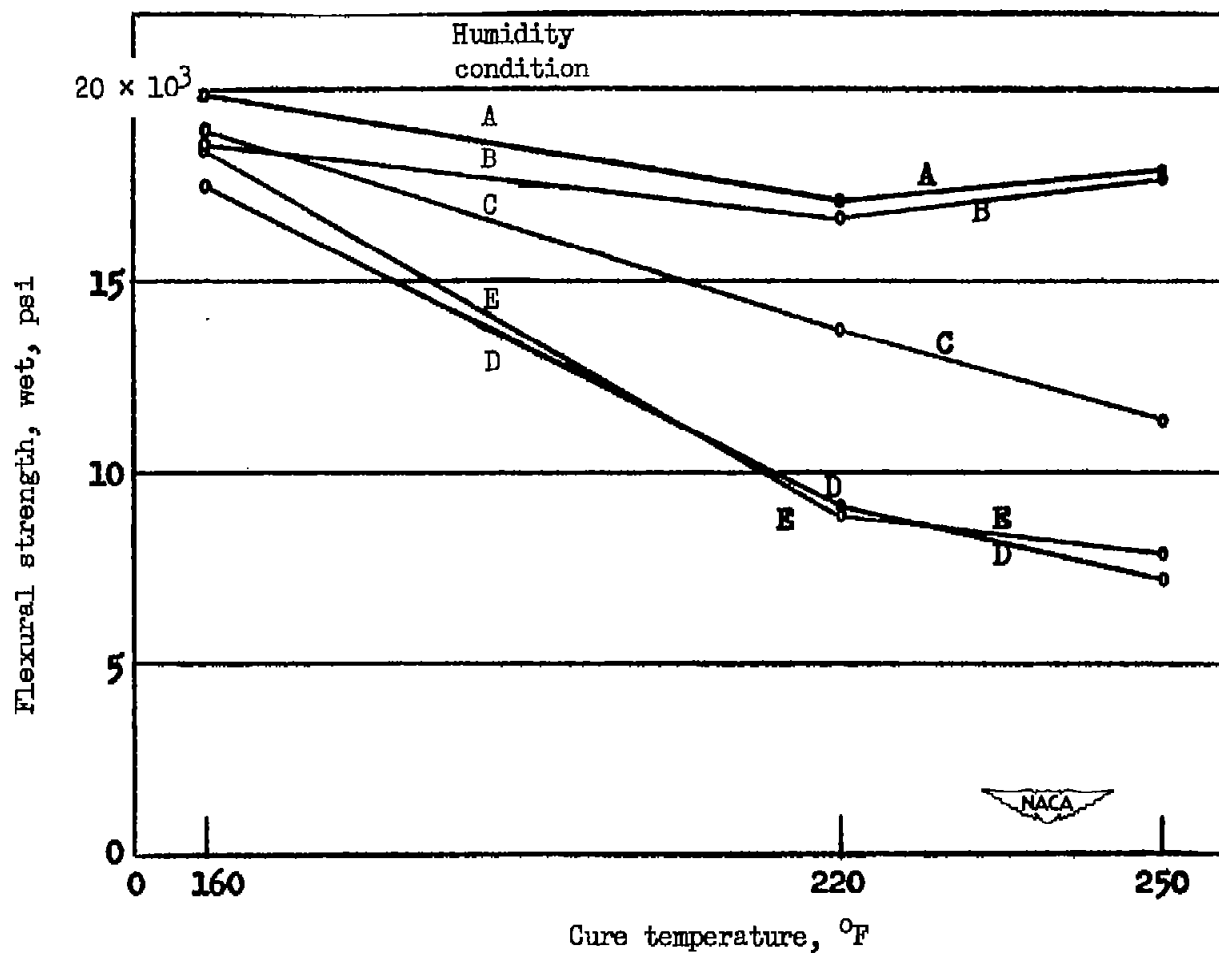


Figure 2.- Effects of cure temperature and humidity during fabrication on wet diagonal flexural strength of Fiberglas 181-114 laminate bonded with Laminac 4126 resin. Data are for laminates molded at 0.7-psi pressure. See footnote a of table III for description of humidity conditions.

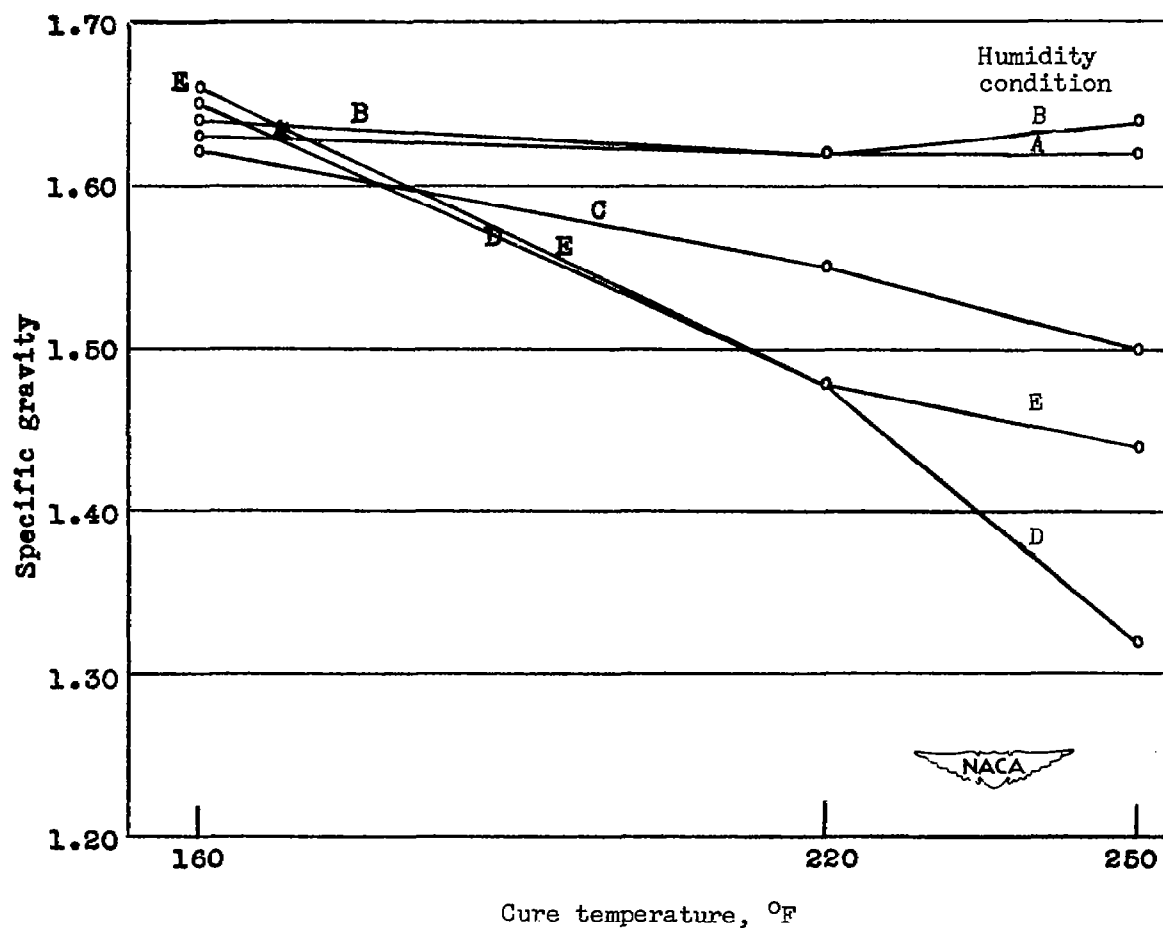


Figure 3.- Effects of cure temperature and humidity during fabrication on specific gravity of Fiberglas 181-114 laminates bonded with Laminac 4126 resin. Data are for laminates molded at 0.7-psi pressure. See footnote a of table III for description of humidity conditions.

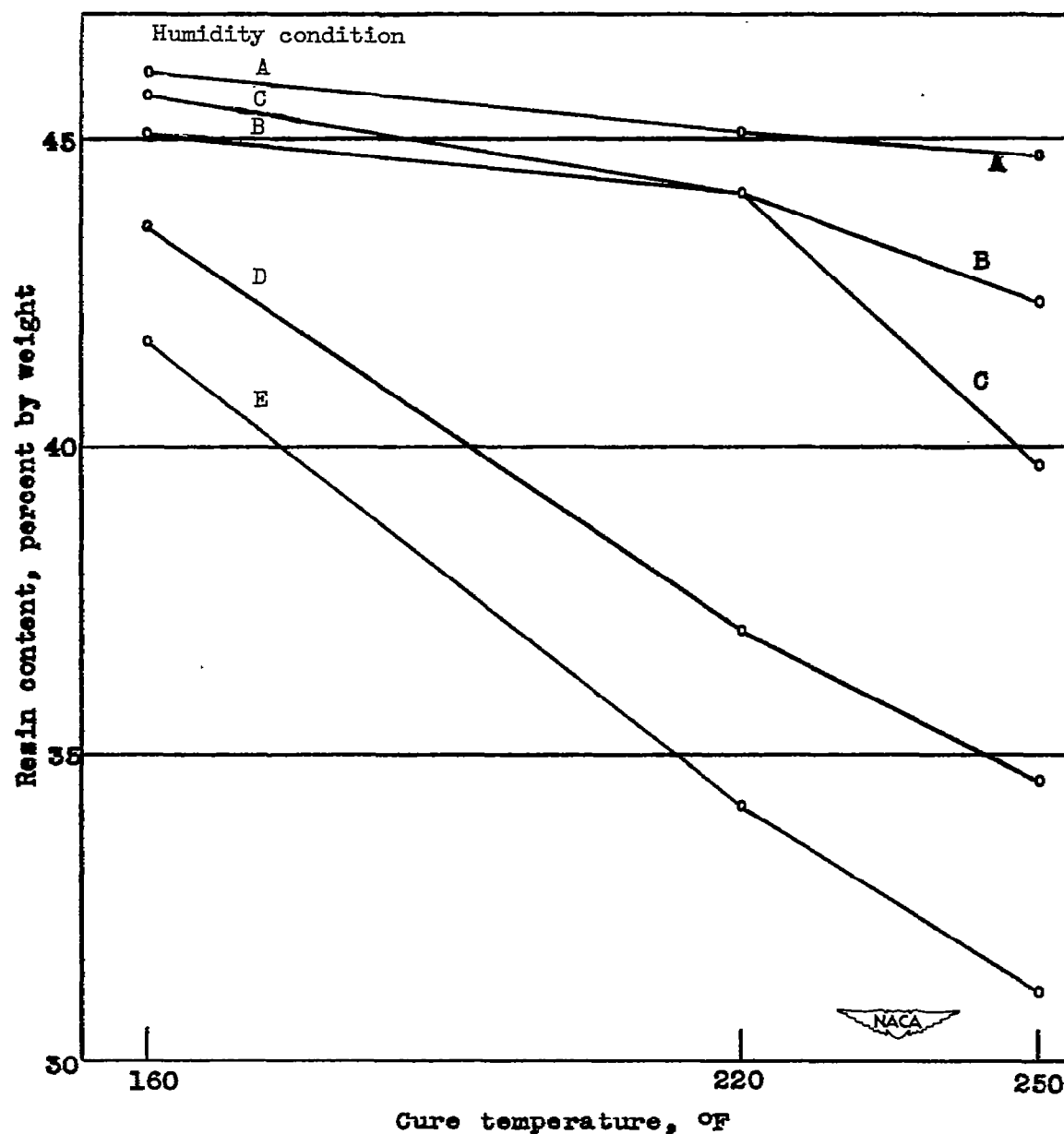


Figure 4.- Effects of cure temperature and humidity during fabrication on resin content of Fiberglas 181-114 laminates bonded with Laminac 4126 resin. Data are for laminates molded at 0.7-psi pressure. See footnote a of table III for description of humidity conditions.



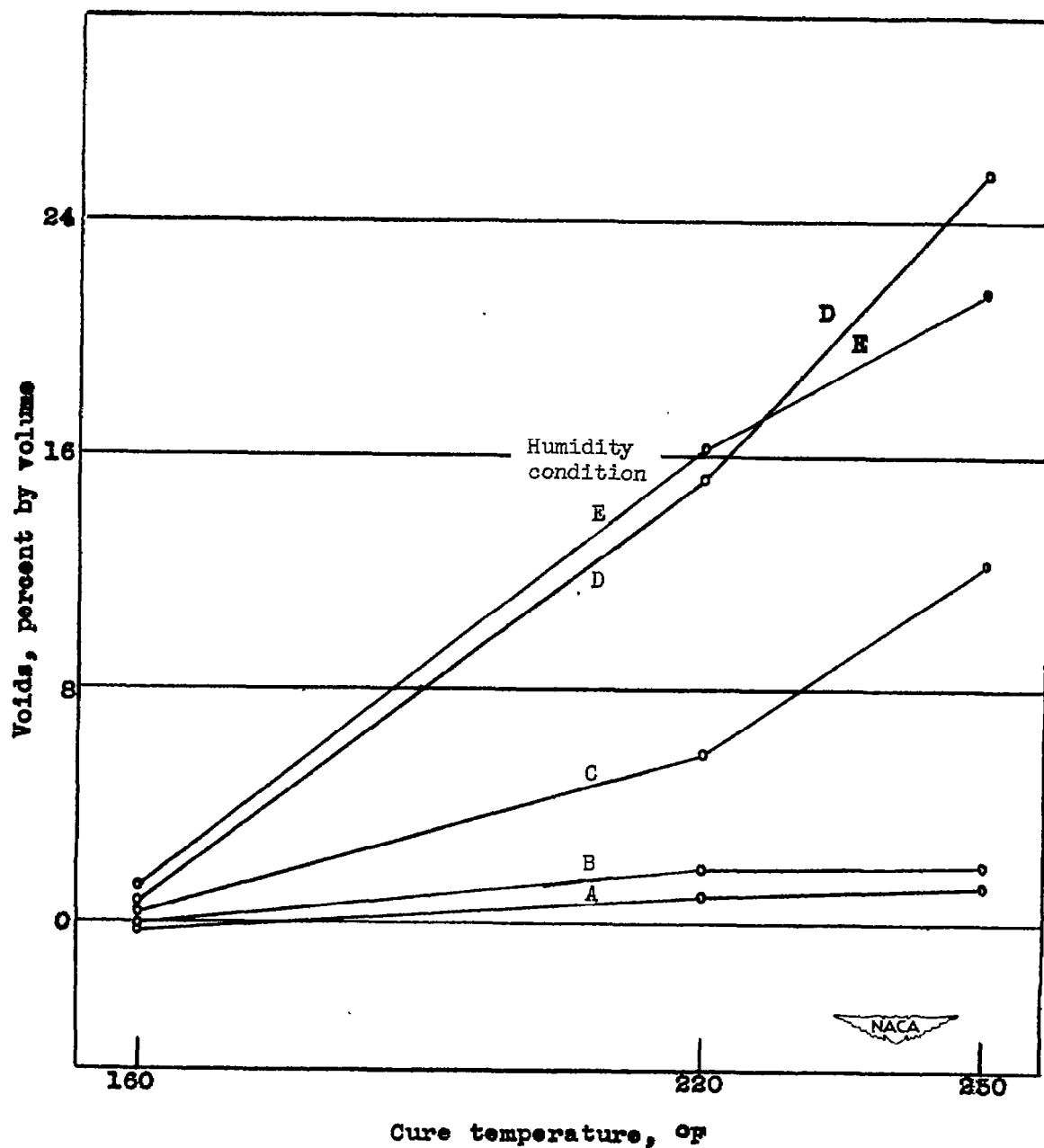


Figure 5.- Effects of cure temperature and humidity during fabrication on percentage of voids in Fiberglas 181-114 laminates bonded with Laminac 4126 resin. Data are for laminates molded at 0.7-psi pressure. See footnote a of table III for description of humidity conditions.

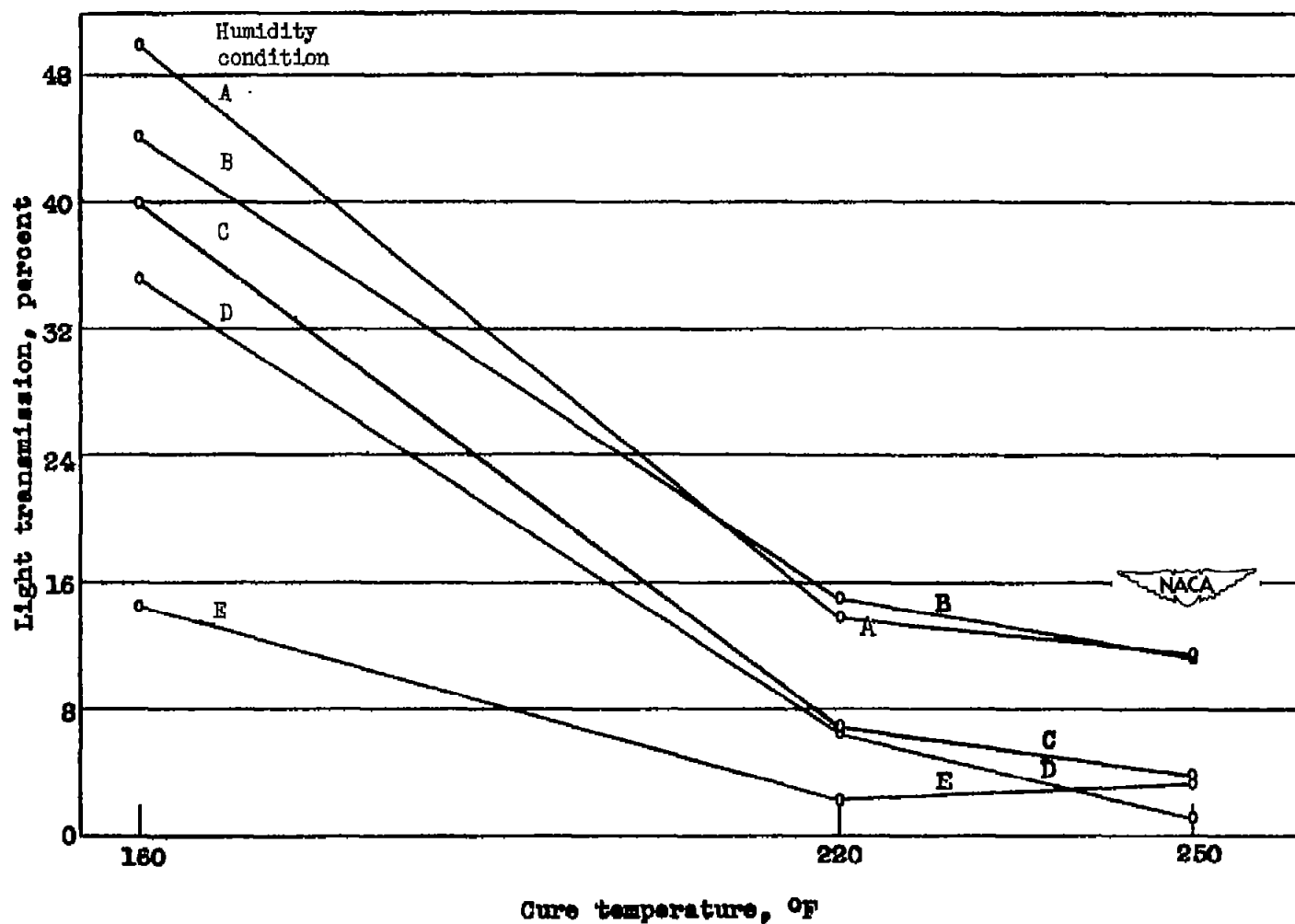


Figure 6.- Effects of cure temperature and humidity during fabrication on light transmission of Fiberglas 181-114 laminates bonded with Laminac 4126. Data are for laminates molded at 0.7-psi pressure. See footnote a of table III for description of humidity conditions.

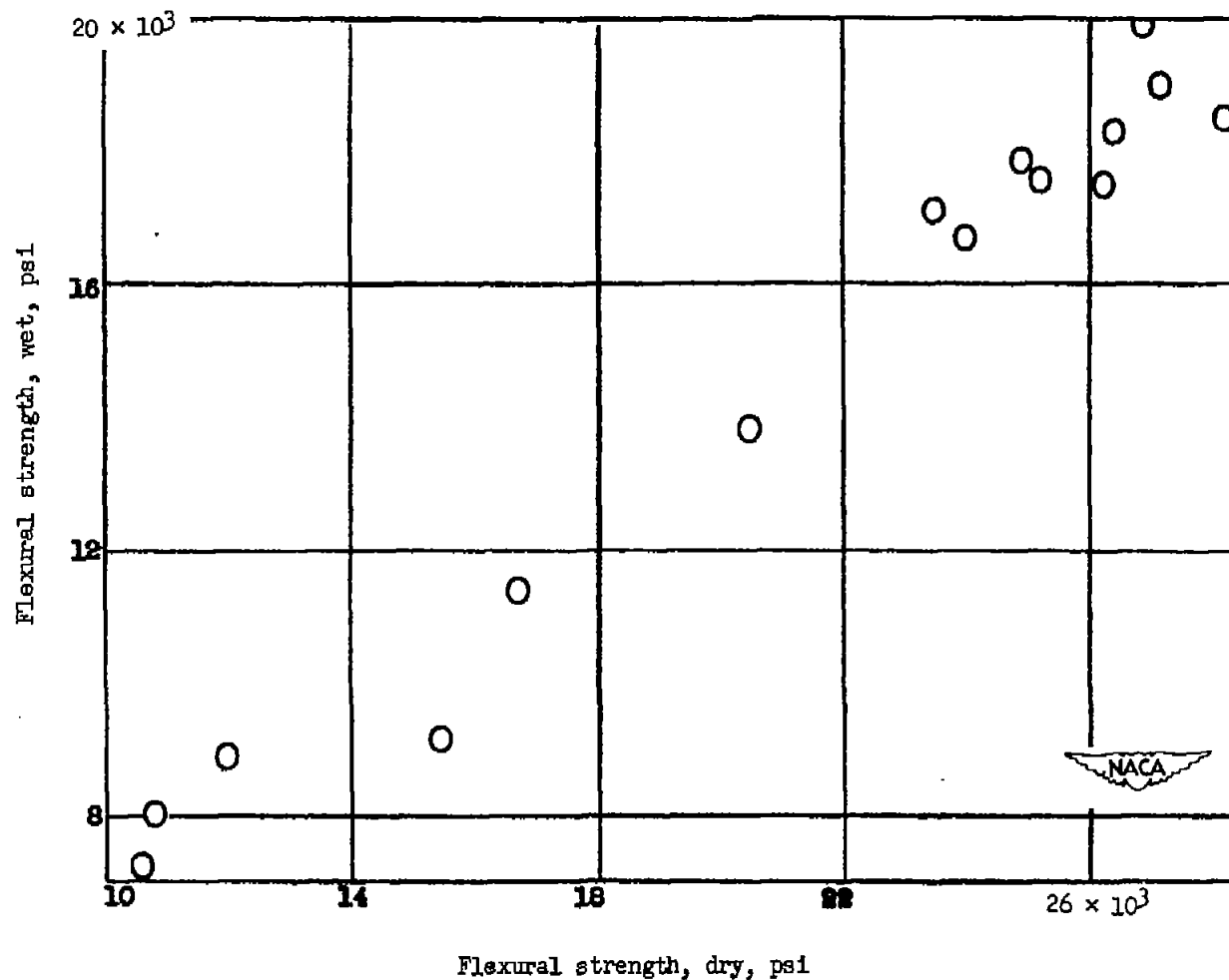


Figure 7.- Relation between dry and wet diagonal flexural strength for Fiberglas 181-114 laminates bonded with Laminac 4126 resin at different molding and humidity conditions. Data are taken from table III for panels molded at 0.7-psi pressure.

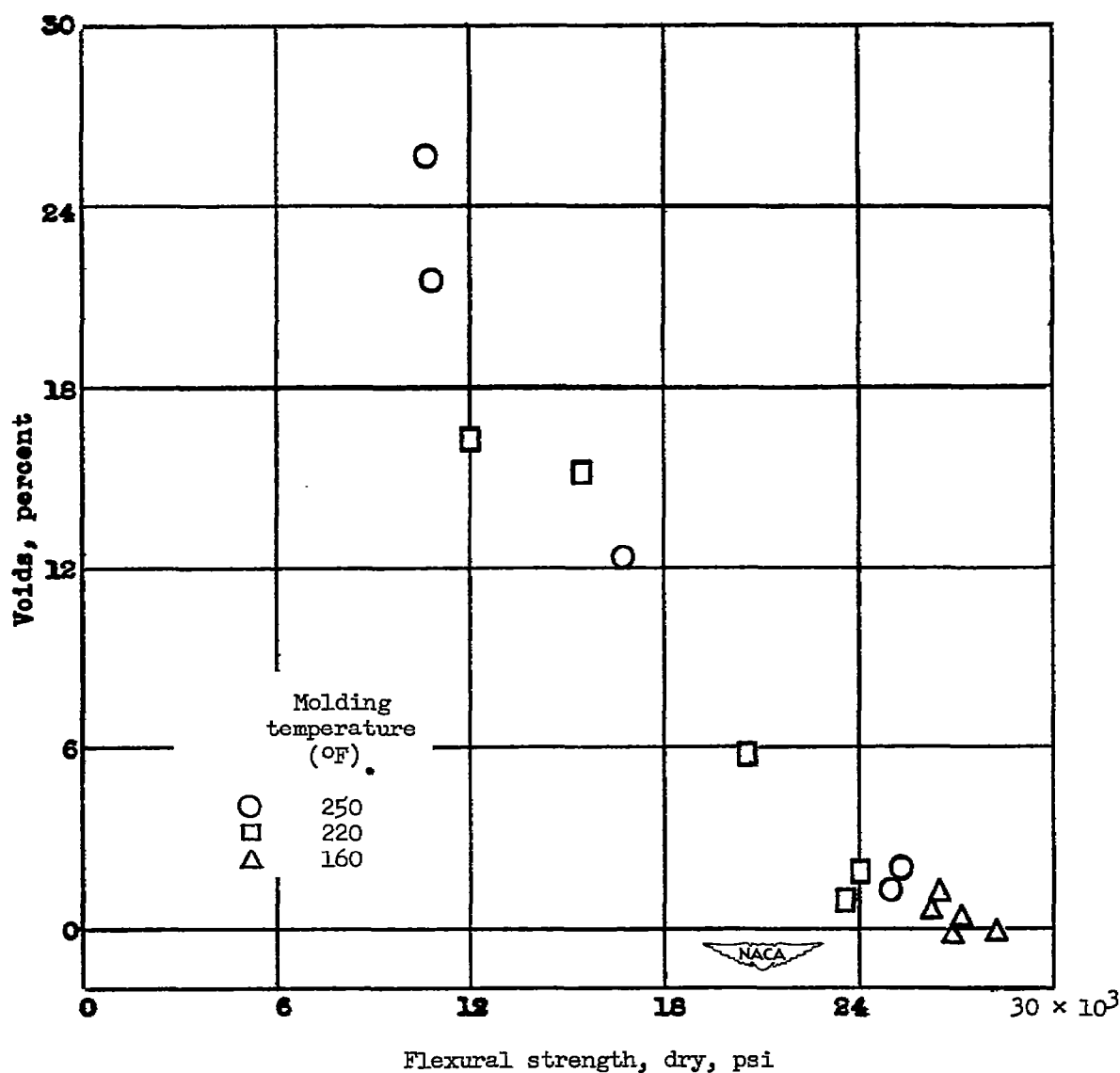


Figure 8.- Relation between percentage of voids and diagonal flexural strength for Fiberglas 181-114 laminates bonded with Laminac 4126 resin at different molding and humidity conditions. Data are taken from table III for panels molded at 0.7-psi pressure.

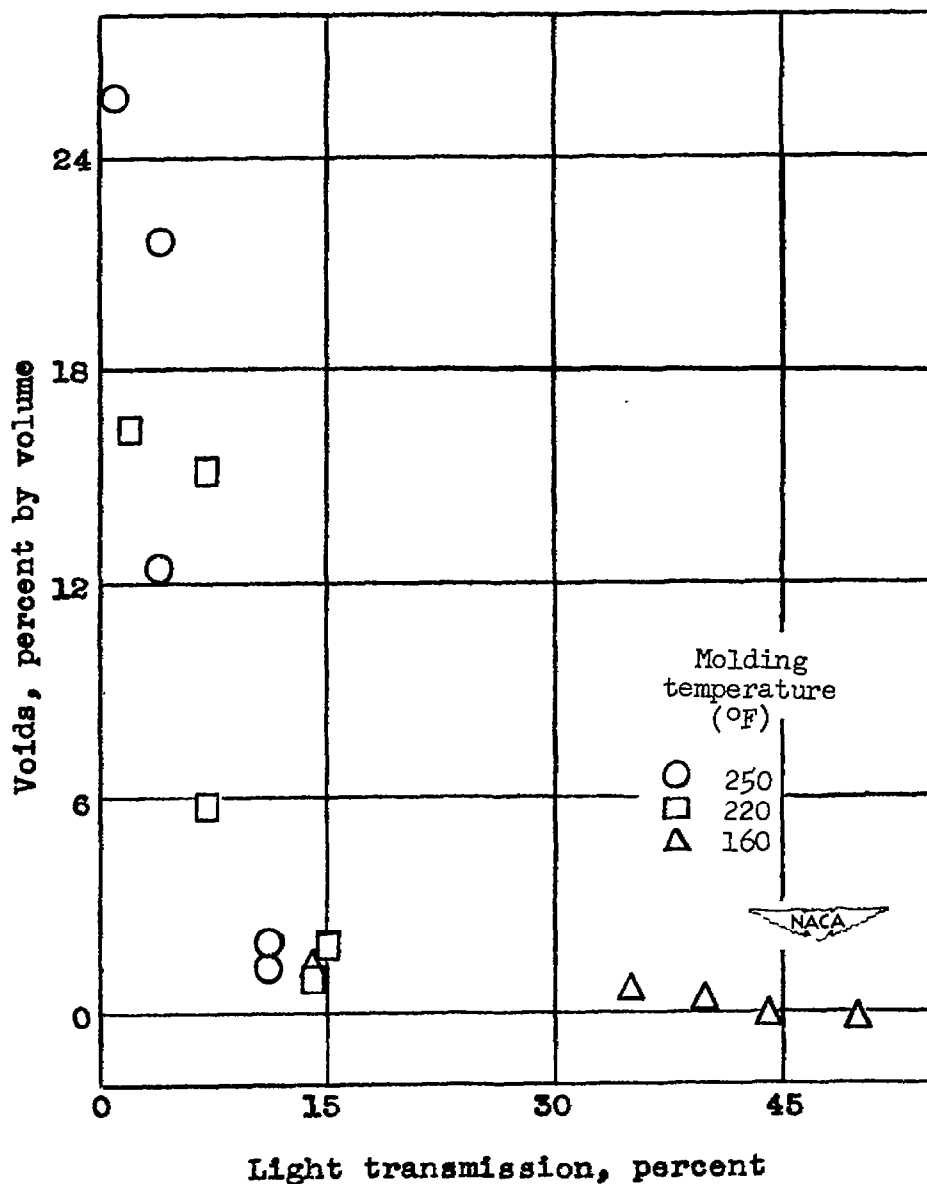


Figure 9.- Relation between voids and light transmission of Fiberglas 181-114 laminates bonded with Laminac 4126 resin at different molding and humidity conditions. Data are taken from table III for panels molded at 0.7-psi pressure.

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